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Abstract -- *The Los Alamos Neutron Science Center (LANSCE) short-pulse spallation source provides neutrons for research at the Lujan Center. We upgraded the target system in 1998 in order to provide neutrons to four new flight paths and to permit the proton beam current to be raised to 200 μA. Since 2000, we have operated the target system with the formality of a DOE Category-3 nuclear facility. We have achieved over 99% availability for the target system for the past two years and we have recently achieved a proton beam current of 125μA. Overall availability of neutrons to the user facility has been over 85%. In 2002 we performed a target change operation. The old system had required five months to change a target. The new system required 37 days and the radiation dose to personnel involved in the change was reduced by a factor of twelve. We review our experience of operating this high-power target system.*

I. INTRODUCTION

The LANSCE linear accelerator provides an 800-MeV proton beam to a proton storage ring (PSR) that stores them and delivers them to the target station in 250 ns-wide pulses at 20 Hz. The target station converts these proton pulses into neutron pulses of the appropriate energy and time spectrum using tungsten targets, water moderators, and liquid hydrogen moderators. The target station then provides these neutrons to the Lujan Center experimental areas where they are used for materials science and basic research.

The original target system was placed in service in 1985 and provided neutrons for twelve flight paths. The major components of this system were replaced in 1991 with new components but without major design changes. We refer to these target systems as the Mark 0a and the Mark 0b target systems.

We redesigned the target system as part of the LANSCE Reliability Improvement Project (LRIP) beginning in 1995. The goals of the target upgrade were: 1) Change out of the target-moderator-reflector system (TMRS) in three weeks or less, 2) Provide partially-coupled upper-tier moderators to service four new flight paths, 3) Increase proton current capability from 70 μA (56 kW) to 200 μA (160 kW), 4) Preserve the neutronic performance of the existing lower-tier flight paths, 5) Operate at 100 μA with 85% availability

We installed the new system following the 1997 operations period that ended in August 1997. The new target, referred to as the Mark 1, was commissioned in October 1998. The target engineering, the upgrade and initial operation have been described previously. [1,2]

II. OPERATIONAL EXPERIENCE

II.A. Commissioning and Initial Operation

We began commissioning on October 25, 1998 and we reached our goal of 100 μA of proton beam current on November 19, 1998. All of the upgraded components worked extremely well. However, we experienced operational difficulties with the water-cooling and liquid-hydrogen support systems. These systems had not been upgraded as part of the LRIP. Leaks of radioactive coolant and other incidents not related to the target system forced LANSCE into a stand down in February 1999. For the Lujan target, this outage lasted for the rest of the calendar year. During this short operating period, we were able to demonstrate that the performance of the lower-tier moderators was preserved and that the target could operate at 100 μA. We were not able to demonstrate 85% availability or learn about the upper-tier moderator performance.

II.B. 1999 Outage Activities

During the 1999 outage, we addressed the reliability issues with the target support systems and prepared the facility to operate with the formality of a DOE Category-3 nuclear facility. Several issues arose with the heating-ventilation and air conditioning (HVAC) system and with the radioactive liquid waste (RLW) system that prolonged the outage. These issues were related to a lack of maintenance and a lack of configuration management. These issues were satisfactorily addressed before the readiness assessment.

The liquid-hydrogen support system suffered from ice blocks and leaks that were traced to leaking compression fittings. Fittings that were exposed to temperature cycling were a particular problem. The fix was to replace compression fittings with either metal-gasket face-seal fittings in locations where disassembly is required or with welded joints in locations where disassembly is not required.

The water system fixes were to install proper drains and to seal cracks in the floor so that small coolant leaks around pump seals could not affect the experimental areas. The systems were also modified to bring them into conformance with code ASME B31.3 including pressure testing. Procedures were also modified to ensure that new components were properly pressure-tested and leak-tested

II.C. Safety Basis

The Lujan target is a Category-3 nuclear facility based upon the isotope inventory under DOE standard 1027-92. We performed a safety analysis according to DOE order 3009 and issued a Basis for Interim Operation (BIO) in December 1999. The BIO identifies the Technical Safety Requirements (TSR) and the Surveillance Requirements (SR) that are necessary for safe operation of the facility. DOE issued a Safety Evaluation Report (SER) in time for a full Readiness Assessment (RA) in March 2000. The RA verified the implementation of the TSRs, the conditions of approval in the SER and the adequacy of the formal conduct of operations, configuration management, and maintenance management. The DOE SER is essentially the license to operate the facility. Although the APT materials-irradiation experiments at LANSCE were also covered by a BIO, the Lujan target is the first accelerator-driven nuclear system to be licensed and operated with the full formality of a DOE Category-3 nuclear facility.

The BIO identifies the design basis accident as a loss of cooling to the tungsten targets and a failure of the safety systems to turn off the accelerator beam. The tungsten targets can then heat up and oxidize in the presence of steam leaving hydrogen in the containment vessel. The tungsten oxide contains radioactive spallation products that can be dispersed if air leaks into the containment and the hydrogen ignites. The primary devices for preventing this accident are redundant, safety-significant, flow switches that provide input to the accelerator radiation security system (RSS). Other TSRs and SRs cover the HEPA filter, the RSS backbone, gamma detectors for sensing beam spill, and a radiation detector that senses the build up of activation products in the HEPA filter.

The facility operation is simplified by the fact that the serious radiation accidents can only take place with the beam on. Thus there are only two MODES; beam allowed and beam-not-allowed. Placing any two out of a possible eleven beam-preventative devices into their beam-preventative configuration defines the beam-not-allowed MODE. The status of the surveillance and inspections is tracked on a status board in the central control room. Operators can tell at a glance if all surveillances are current and entry to the beam-allowed mode is permitted.

II.D. 2000 Operation

Following the successful closure of the pre-start findings from the readiness assessment, we resumed beam delivery on June 17, 2000. We delivered beam at a nominal beam current of 100 μA for the rest of calendar year 2000 with an availability of 97.3%. The 2.7% of down time ascribed to the target was mainly due to air eliminators in the target water system. These air eliminators were not sized properly for the gas production that occurs when the proton beam interacts with the tungsten target and the water coolant.

One of the major issues with the old (Mark 0b) target was corrosion of the primary tungsten targets. Corrosion products were trapped in the piping and air eliminators. During the LRIP upgrade, the coolant piping was reading up to 1 R/h at contact several months after the beam was turned off. The air separator over the water pumps was reading 160 R/h. After a year's operation with the new target, the coolant piping and air separator were only reading 20 mR/h. The new (Mark 1) target uses pure tungsten that is much less susceptible to corrosion as compared to a tungsten alloy for the old target.

The hydrogen moderator system was originally designed to operate at constant pressure. Following advice from our hydrogen safety review committee, we have operated the system in the constant mass mode after it was filled. This has the advantage that there is no path for contaminants to enter the system. The disadvantage is that there is a pressure differential between beam-on and beam-off. This is manageable at 100 μA but these pressure variations may become unacceptable as we go to higher beam currents.

The low total beam availability of 74.7% to the Lujan Center was due to problems with site power and the accelerator radio-frequency systems. These problems were overcome in time for calendar year 2001 operation. We ceased the 2000 operations cycle on December 24, 2000 and entered an outage for extended maintenance.

II.E. 2001 Operation

We began year 2001 operations in July 2001 and delivered beam at a nominal beam current of 100μA. All systems operated satisfactorily until we encountered an overheating problem in the lower lead reflector. Our trending analysis indicated that this component had been deteriorating since it was first placed into service. The design had stainless steel cooling lines cast into lead. We believe that thermal cycling due to the beam begin turned on and off caused the lead to eventually break away from the cooling lines. In order to avoid melting the lead and thus getting volatile spallation products into the vacuum system, we were forced to limit the proton beam current to 55 μA.

Our trending analysis also indicated that the upper target-cooling manifold had developed a shunt so that approximately half of the coolant was bypassing the tungsten plates. This was a more serious issue than the lead reflector since a cooling failure in this circuit can be an initiator for the design basis accident. For this reason, we performed a safety analysis and applied to the DOE for a Justification for Continued Operation (JCO). The analysis indicated that the system was safe to operate provided that we kept the current below 75 μA. Our DOE safety-basis management was very supportive and they approved the JCO in a working session that lasted over the holiday weekend of October 6-8, 2001.

Because of the limitations to operation, we began to construct another version of the target insert and plan for a target change during the 2002 maintenance outage. The new insert was identical to the old insert except for changes to the components that had limited the beam current during 2001 operation. The design for the lower lead reflector was changed to beryllium-stainless steel composite and the design for the upper lead reflector was changed to stainless steel. The upper lead reflector had not failed but our trending analysis showed signs of degradation. The upper target coolant manifold design was changed to have a better weld prep and to eliminate the possibility of an internal shunt.

II.F. 2002 Outage: Target Change Operation

The target was changed during the maintenance outage. The target change operation demonstrated that we could change a target in thirty working days. This is longer than the two to three weeks as in the original goal, but that goal was set before we knew that we would have to operate with the formality of a Category-3 nuclear facility. The target change operation is described in detail in another paper.[4] The old target was retained as a spare since it is still serviceable even though the proton beam current is limited.

II.G. 2002 Operation

Operations with the new (Mark 2) target started in July 2002 and we ran through the calendar year until January 2003. All systems worked well and we were able to reach a record proton beam current of 125 μA (100 kW) and a record beam delivery for one year of over 270 mA-h. Considering the time that we ran in January 2003, we delivered 304 mA-h to the target during a single operations period.

III. OPERATIONS SUMMARY

Table I gives a summary of the availability and total charge delivery to the target since 2000. The Lujan Center availability is the net availability of neutrons to the flight paths including the effects of all beam delivery systems. It does not include the effects of experimental instrument availability. Although the availability was quite good for 2001, the integrated current was lower because of the 55 μA current limit.

The moderator performance has been very nearly as calculated by the target physics team.[4] The exception is the upper-tier water moderator that appears to have a lower flux than was calculated. This issue is still under review by LANSCE staff.

Table I. Target availability, Lujan Center availability and integrated current (total charge) delivered by calendar year			
Year	Target System Availability	Lujan Center Availability	Integrated Current (mA-h)
2000	97.26 %	74.7 %	197
2001	99.16	90.0	189
2002	99.21	86.6	271

IV. FUTURE PLANS

Our long-term plan is to increase the beam current up to the 200 μA design current and to decrease the time spent for maintenance so that more time goes to production. These goals will require an upgrade to the accelerator source and improvements to the target support systems. The liquid-hydrogen heat exchanger will require an upgrade to deal with the increased power. The liquid-hydrogen and water-cooling systems will need improvements to ensure that they can operate reliably at high power. Higher power levels and reduced cool-down time due to reduced maintenance schedules will increase radiation exposure to personnel. The systems will have to more reliable and will have to have remotely operated valves in order to reduce radiation exposure to personnel.

The present safety analysis and authorization basis only supports operation up to 150 μA. An increase in the beam current beyond this acceptance limit will required an further analysis and amendment to the authorization basis. The present BIO is due to be replaced with a new Documented Safety Analysis (DSA) in April 2004 and we hope that the necessary change can be incorporated into that document.

V. ACKNOWLEDGMENTS

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